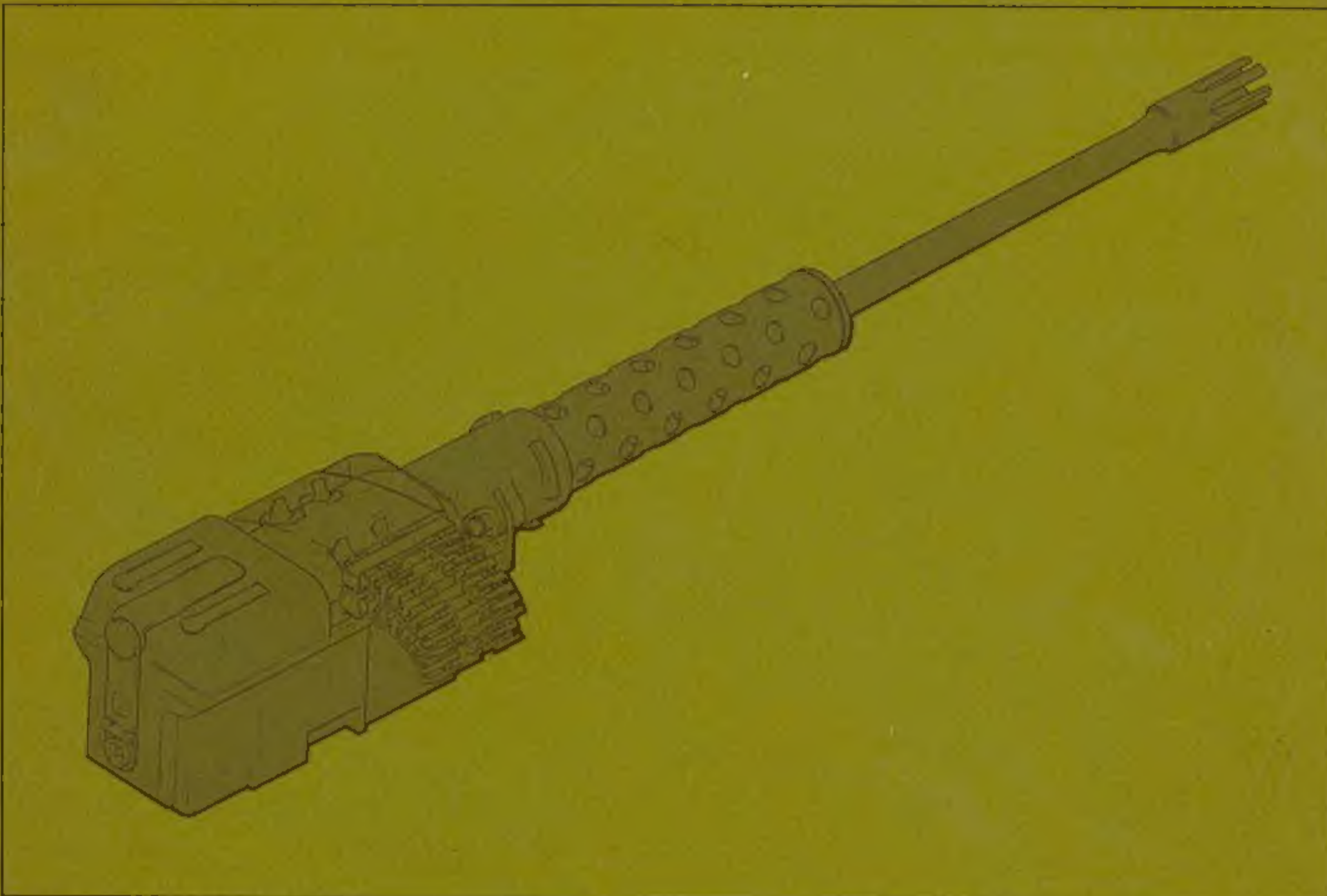


HUGHES GUN SYSTEMS

HTC-AD 71-59

HUGHES 7.62MM EXTERNALLY POWERED
ARMOR MACHINE GUN

PROGRESS REPORT 3
8 March 1971 Through 9 June 1971

Contract DAAF03-70-C-0011

10 June 1971

HUGHES TOOL COMPANY-AIRCRAFT DIVISION / CULVER CITY, CALIFORNIA

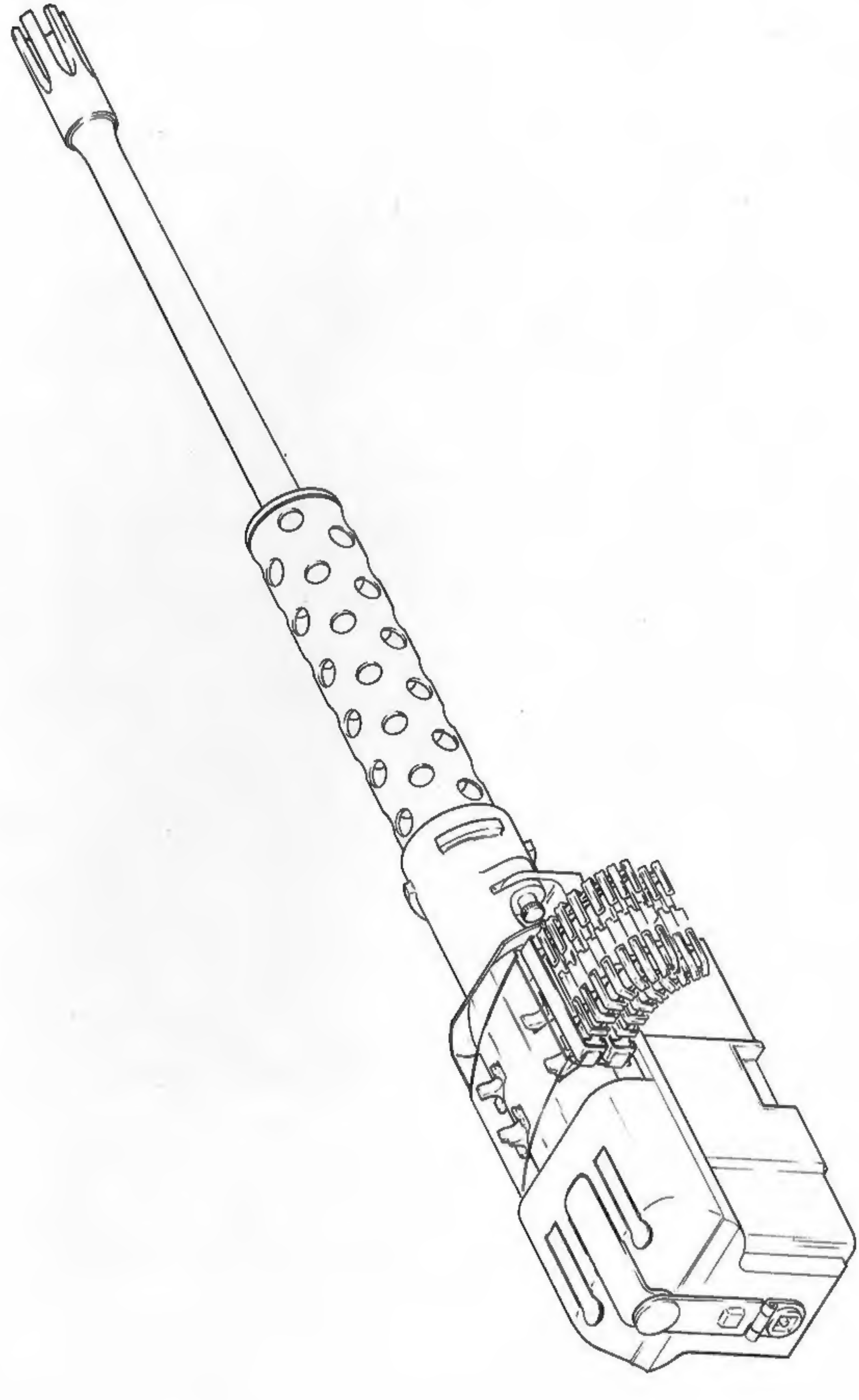
HTC-AD 71-59

HUGHES 7.62MM EXTERNALLY POWERED ARMOR MACHINE GUN

PROGRESS REPORT 3
8 March 1971 Through 9 June 1971

Contract DAAF03-70-C-0011

10 June 1971



Frontispiece

TABLE OF CONTENTS

INTRODUCTION

The Externally Powered Armor Machine Gun (EPAM) shown in the frontispiece and the proposed layout (Figure 1) is being designed and developed and a model is being fabricated under Contract DAAF03-70-C-0011 with U. S. Army Weapons Command. The primary characteristics of the EPAM design are:

- Externally powered
- Dual feed
- 600 shots per minute
- Cam operated
- Single barrel, quick replacement
- 7.62mm NATO ammunition and M13 link
- Compact size, the same as M73
- Sprocket feed

While this initial design is scaled for 7.62mm NATO, the general concept is adaptable to a range of calibers through 30mm.

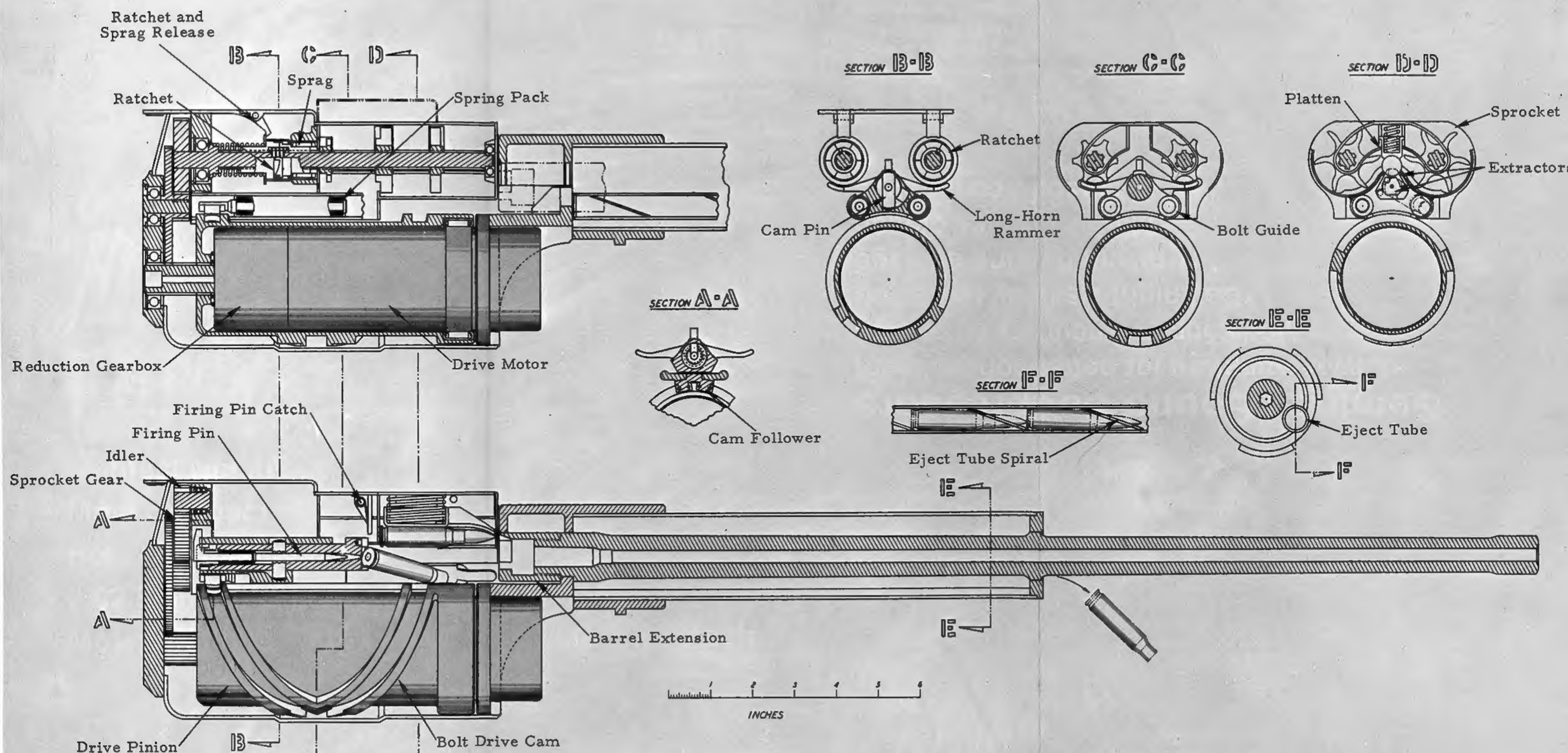


Figure 1. Layout - Externally Powered Armor Machine Gun

SUMMARY

The Third Contract Review meeting was held at Hughes Tool Company - Aircraft Division, Culver City, California, on 8 March 1971. The second progress report was delivered and a review was made of work accomplished to that date. Specific items discussed included the following:

- Status of system design
- Level of stress analysis required on model
- Necessity for spring packs on bolt carrier
- Extent of breadboard testing
- Complete review of system math model
- Changes and additions to system math model
- Possibility of a 10-percent cost overrun resulting from a change in HTC-AD's general engineering overhead

For the 8 June 1971 Contract Review, the system math model has been completed and now includes all changes requested during the previous review. The gun system layout is complete, as are all details of the bolt, motor/cam drive, and significant portions of the feed systems. The bolt has been released for fabrication and the cam has been completed (Figure 2).

In addition, an investigation has been made of the contractual obligations and remaining funds in an effort to reduce the impact of the increase in the general engineering overhead and G&A rate. The object of this study is to identify the most significant portions of the scope of work that can be completed within the funds available.

During the coming period, it is anticipated that the following work will be accomplished:

- Complete detail design
- Initiate fabrication of all components
- Assemble bolt, cam, and drive assembly

Figure 2. Bolt Drive Cam

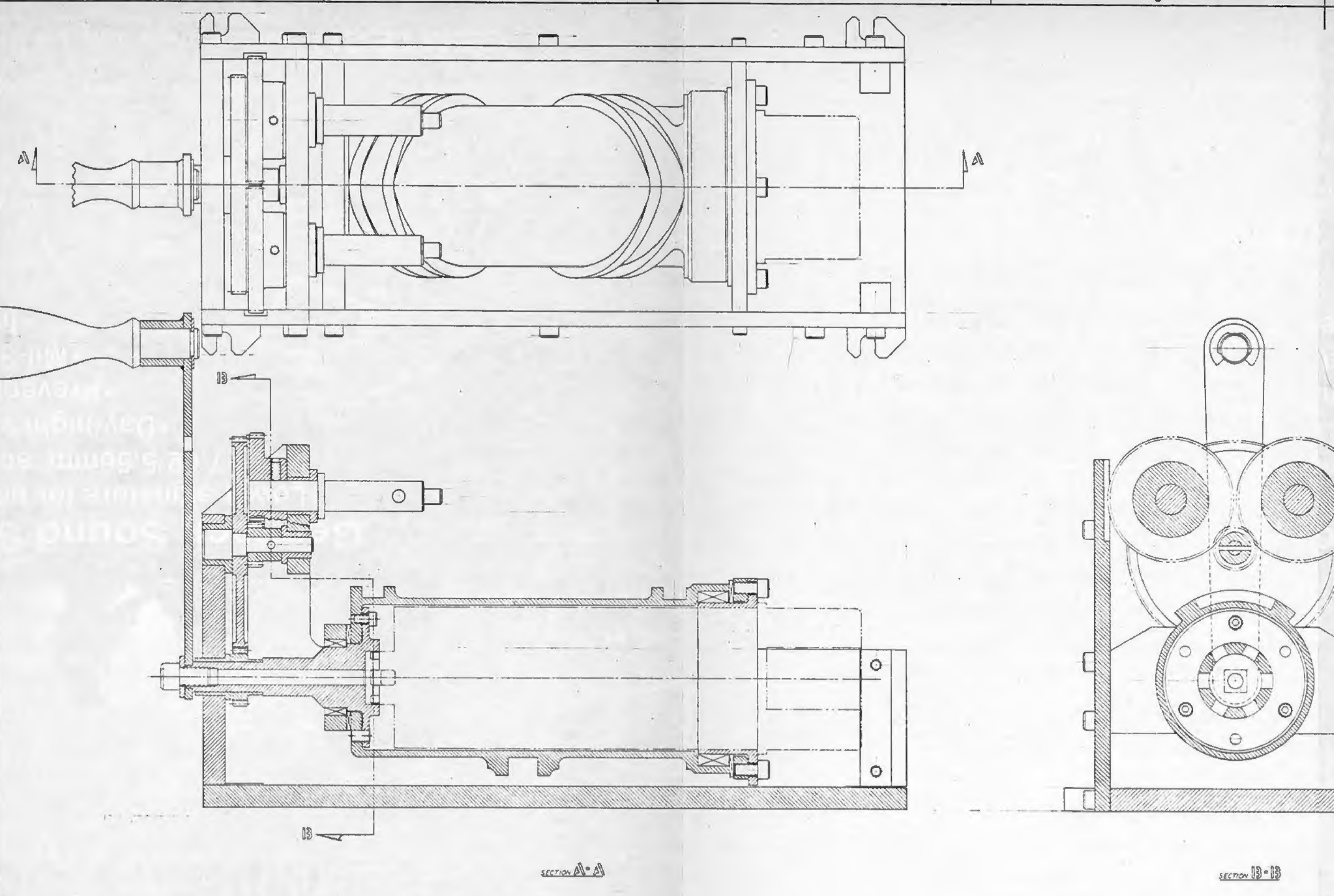
SYSTEM DESIGN

System design is proceeding extremely smoothly and on schedule. The final layouts have been completed and detail design is 40 percent complete. The cam and bolt group have been released for fabrication.

A number of representative drawings are included in this report (Figures 3, 4, and 5) to illustrate some of the design work accomplished during this period.

Of particular interest is Figure 3, which shows the proposed conformation of the model's cam and drive system. A hand crank system of operation is shown; the installation of an electric motor has been eliminated in order to conserve funds but is shown in phantom line. Also shown in this drawing is the simplified construction by means of flat plates and cap screws that is being used to reduce construction costs.

Included in the Appendix to this report is a stress analysis of the firing pin spring and bolt that have resulted from the redesigned bolt system. This system allows for significantly lower firing pin stress, easier disassembly, and stronger construction than that originally proposed.



LIST OF MATERIAL

QTY REQD | PART NO | NAME | SIZE | DESCRIPTION | SPECIFICATION | ZONE

APPLICATION (USAGE) DATA

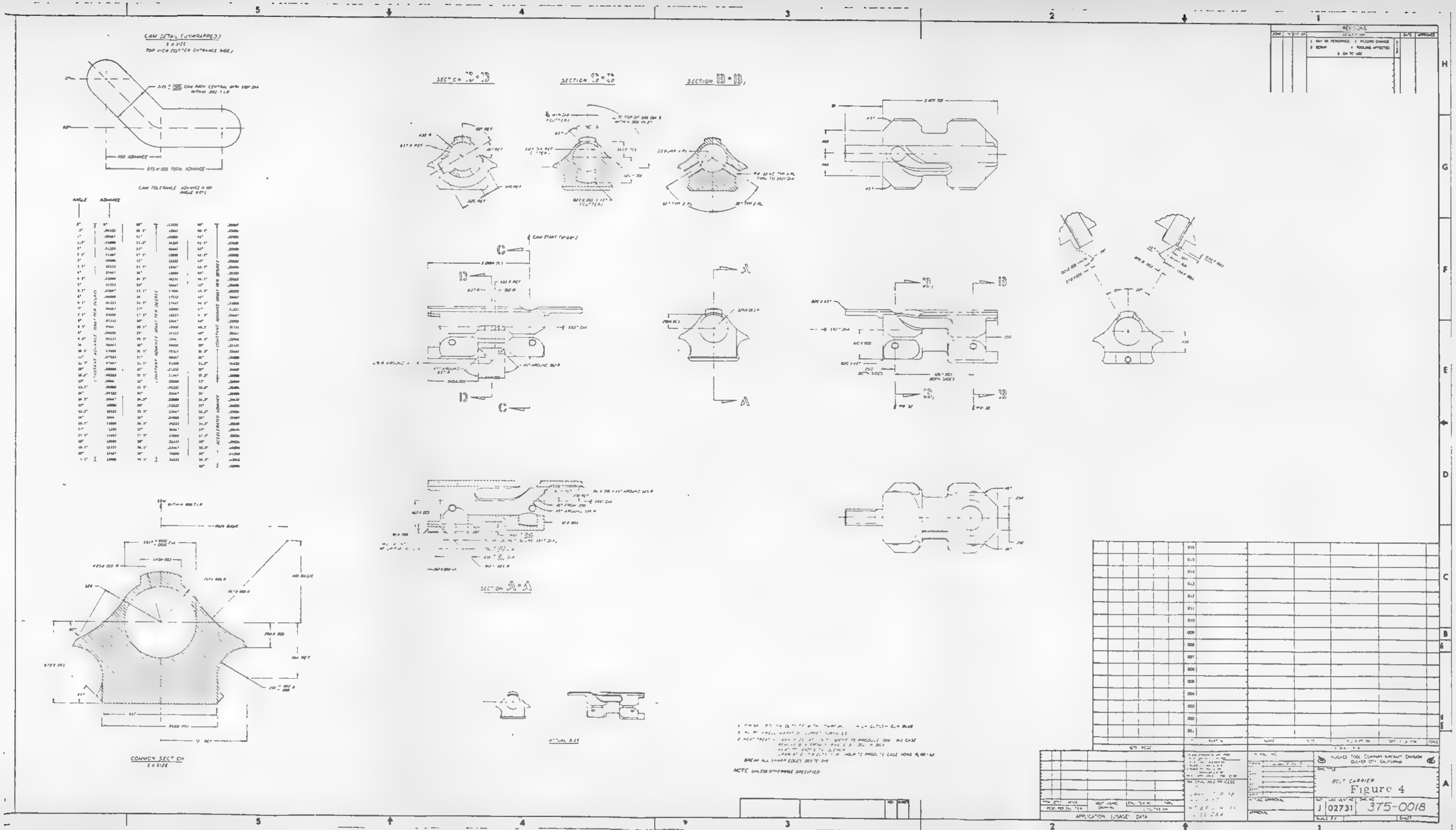
MATERIAL AND PROCESS
SEE MATERIAL LIST

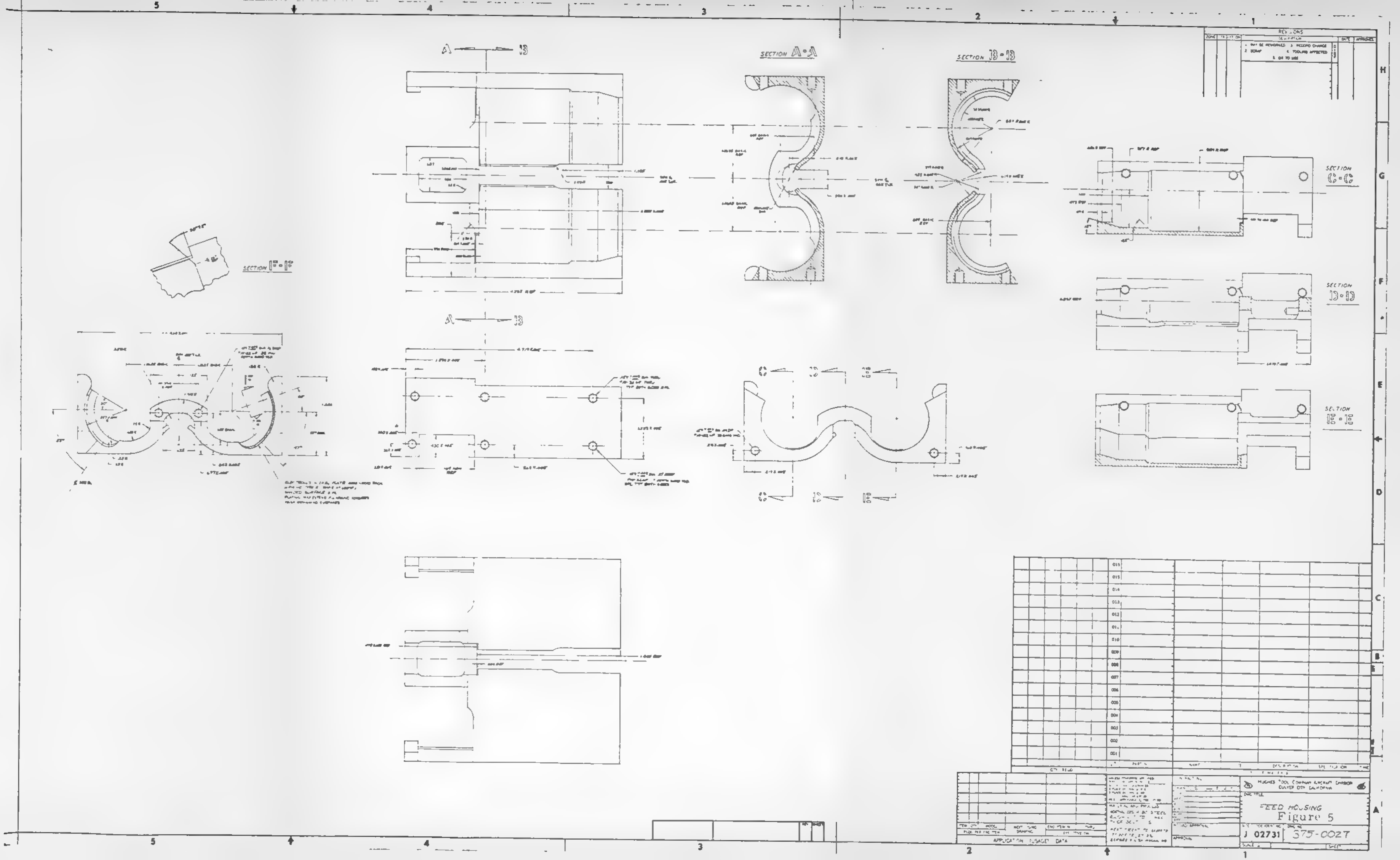
CONTRACT NO

HUGHES TOOL COMPANY AIRCRAFT DIVISION
CULVER CITY, CALIFORNIA

DWG TITLE
DRIVE TRAIN ASSEMBLY
Figure 3

SIZE J | CODE IDENT NO 02731 | DWG NO 375-0028


CAM DETAIL (UNWRAPPED)
SECTION B-B
SECTION A-A
COMMON SECTION
REVISIONS
NOTE UNLESS OTHERWISE SPECIFIED
APPLICATION (USAGE) DATA
HUGHES TOOL COMPANY AIRCRAFT DIVISION
CULVER CITY CALIFORNIA
BOLT CARRIER
Figure 4
J
02731
375-0018


SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
REVISIONS
HUGHES TOOL COMPANY AIRCRAFT DIVISION
CULVER CITY CALIFORNIA
FEED HOUSING
J 02731
375-0027
APPLICATION USAGE DATA
Figure 5

COST REDUCTION

An increase in the Company Engineering overhead and G&A rates effectively reduces the remaining funds available for completion of the design and fabrication of the gun model on this contract. To absorb the effect of this reduction -- thus avoiding a 10-percent contract overrun -- and still permit the completion of the important aspects of the Scope of Work, certain changes in the program are recommended, as follows:

1. Forward ejection will be eliminated from the model and in its place a simple side-ejection system will be utilized. This is not necessarily a permanent change, and forward ejection can be reinstated at a later date if funds were to be made available.

2. The model will be hand powered by a crank rather than electrically driven. Provisions can be made for the later addition of an electric motor and control box.

3. All planned travel to WECOM by HTC-AD personnel on this contract will be eliminated and those travel funds will be applied to the engineering task.

4. The overall construction of the gun model will be simplified and such niceties as simple "takedown" have been eliminated. The essential elements of the EPAM concept will be clearly illustrated, but nonessential items will not.

5. Scheduled breadboard testing will be eliminated and all testing will be done at the completion of the model.

6. Reports will be simplified.

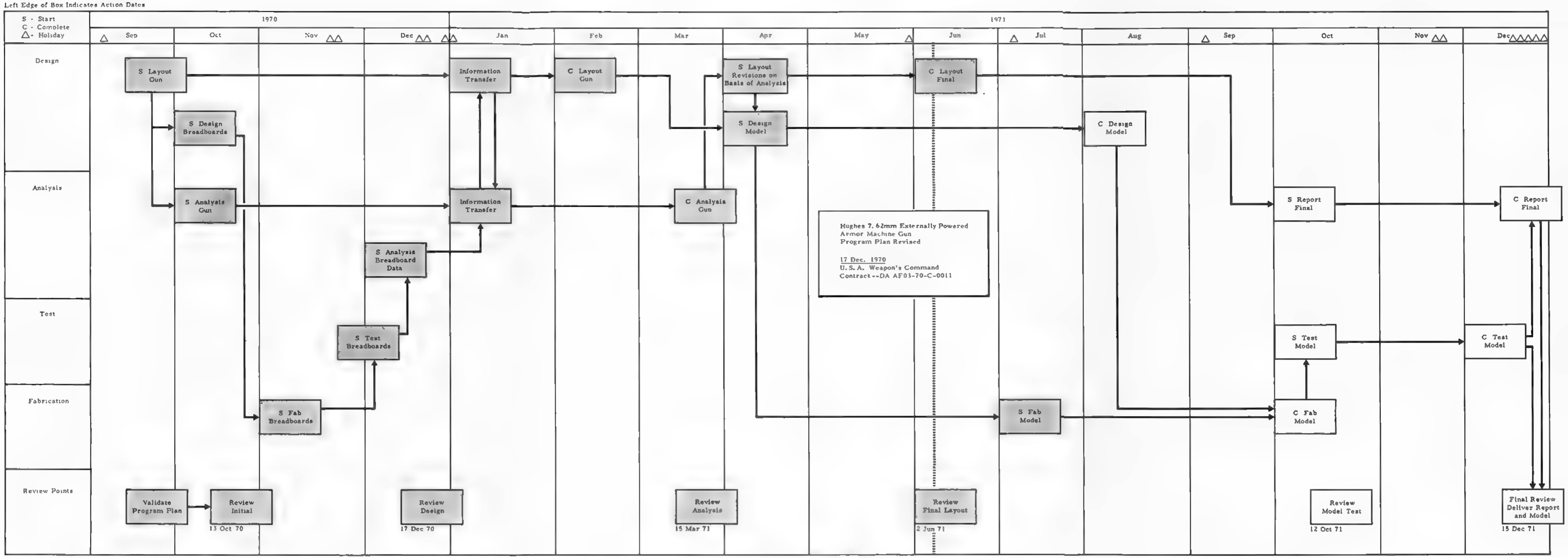
7. It is recommended that one review meeting and report be eliminated and that the program schedule be revised as shown in Figure 6.

With these changes and an anticipated reduction in the estimated cost of model fabrication, it is hoped that the program can be completed within the available funds.

MATH MODEL

The mathematical model of the EPAM system has been completed and the changes and additions requested during the last program review have been incorporated. In view of the funding situation, no further expansion of the model is planned.

A complete and corrected version of the math model is included in the Appendix to this report.



EXTERNALLY POWERED ARMOR MACHINE GUN PROGRAM PLAN

Figure 6. Schedule

APPENDIX

HUGHES TOOL COMPANY-AIRCRAFT DIVISION

ANALYSIS	MODEL	REPORT NO.	PAGE
Firing Pin Energy	EPAM		1 of 1

PREPARED BY L.J. Sullivan 1-29-71

CHECKED BY

All fire Limit .308 NATO is 45 "oz. x 2 = 90"oz ÷ 16 = 5.62"# desired E

Spring .365 O.D. − .055 W.D. = .310 M.D.

13 Total coils ends closed & ground 11 active coils
solid H .770 before grind, .720 After grind
rate = 40.5 #/in

$\Delta f = WH_2 - WH_4 = .406$ av. P = 5.62"# (E) ÷ .406 (Δf) = 13.8#

$\Delta P = .406''(\Delta f) \times 40.5\#/in\ (rate) = 16.42\#$

$P_2 = 13.8\#(av.P) - \frac{16.42}{2}\#(\Delta P) = 5.59\#$

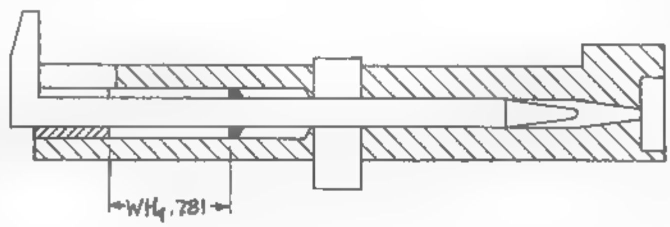
$P_4 = 13.8\#(av.P) + \frac{16.42}{2}(\Delta P) = 22.01\#$

Free H = $\frac{P_4}{rate} + WH_4 =$

$\frac{22.01\#}{40.5\#/in} + .781 = 1.325$

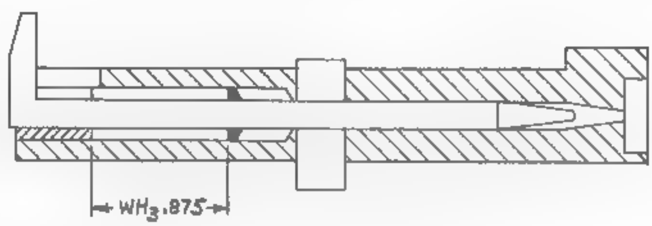
Full Cock

$f_4 = .544$
$P_4 = 22.01\#$
$S_4 = 133,000$



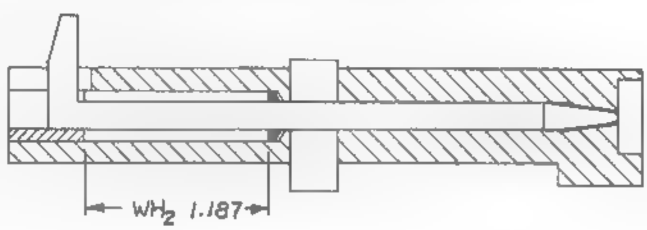
Half Cock

$f_3 = .450$
$P_3 = 18.4\#$
$S_3 = 112,000$



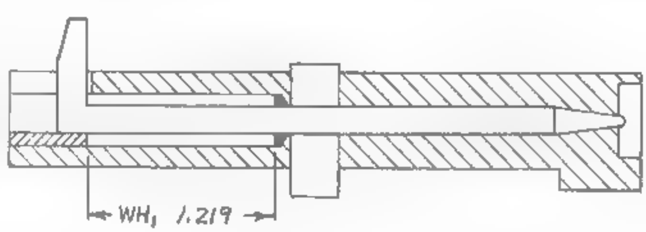
Ignition

$f_2 = .138$
$P_2 = 5.59\#$
$S_2 = 34,000$



End of Driven Travel

$f_1 = .106$
$P_1 = 4.29\#$
$S_1 = 26,000$



9704

HUGHES TOOL COMPANY-AIRCRAFT DIVISION

ANALYSIS Firing Pin Velocity	MODEL	REPORT NO.	PAGE
PREPARED BY Jim Sullivan 6-8-71	EPAM		1 of 1
CHECKED BY			

Known

$W = .03^{\#}$ $(.026^{\#}\text{ f.p.}, .001^{\#}\text{ yoke}, .004^{\#}\text{ spring})$

$S = .\frac{406}{12}{}'$ $(1.187'' WH_2 - .781'' WH_4)$

$F = 13.8^{\#}$ $\left(\frac{22^{\#} P_4 + 5.6 F_2}{2}\right)$

$$V = \sqrt{\frac{2GSF}{W}} = \sqrt{\frac{64.32 \times .406 \times 13.8}{.03 \times 12}} = \sqrt{999}$$

$V = 33.3$ fps

9704

HUGHES TOOL COMPANY-AIRCRAFT DIVISION

ANALYSIS Locking Lug Shear Strength MODEL REPORT NO. PAGE
PREPARED BY J. Sullivan 3/80/71 EPAM
CHECKED BY

force = $.225 r^2 \pi \times 80{,}000$ Psi = 12,700 #

shear area = .406 x .32 x 3 = .389 sq in

shear S = $\frac{12{,}700}{.389}$ = 33,000 psi (with 80K proofround)

material (Carpenter 158) shear strength = 112,000 psi

Safety factors 3.4 : 1 (proof rounds)
5.65 : 1 (standard Ammo)

Comment: 1 lug will hold max proof round

EPAM MATH MODEL

A computer math model to simulate the Hughes 7.62mm Externally Powered Armor Machine Gun (EPAM) has been formulated and programmed as part of this effort. The math model utilizes the Tymshare, Inc., Super Fortran language (IBM Level H Fortran IV).

DEFINITION OF SYMBOLS

a	= acceleration of belt
b	= moment of belt
c	= moment arm for rotating track reactions
d	= distance, cg of bolt to center of cam roller surface
e	= distance from roller center to nearest track contact point
C_r	= coefficient of restitution for bolt-carrier impact
F	= driving force
F_a	= axial inertial force of bolt and round or of bolt and case
F_1	= force required to drive ammunition belt
I_{equiv}	= mass moment of inertia of all rotating parts
L	= length of bolt travel
M	= $M_B + M_C$ = mass of bolt unit + mass of carrier
M_B	= mass of bolt
M_C	= mass of carrier
N	= normal force on roller
N_a	= axial component of the normal force of the roller
N_t	= transverse component of the normal force of the roller
R	= radius of feed sprocket
R_c	= cam radius
R_{fr}	= frictional resistance due to track reactions
R_r	= track reactions due to rotational forces
R_t	= track reactions due to tipping forces
T_{cam}	= torque about gun axis
V_B	= axial velocity of bolt
V_C	= axial velocity of carrier
WT_{belt}	= total weight of ammunition belt
Y	= axial displacement of bolt
$\dot{Y}$	= axial velocity of bolt
$\ddot{Y}$	= axial acceleration of bolt
α	= angle of cam path (slope)
θ	= angular displacement of rotor
$\dot{\theta}$	= angular velocity of rotor
$\ddot{\theta}$	= angular acceleration of rotor

μ = load factor for ammunition belt
μ_r = coefficient of rolling friction
μ_t = coefficient of friction of track

MODEL OPERATION

Basically, the model works with the following equation of motion.

EQUATION OF MOTION

$$\left(I_{cam} + I_{feed} + I_{gears}\right)\ddot{\theta} = T_{motor} - T_{cam} - T_{frict} - T_{belt} \qquad \text{(IA)}$$

where

I_{cam} = moment of inertia of cam
I_{gear} = Σ moments of inertia of gears weighted for any reduction factor
I_{feed} = moment of inertia of feed sprockets and rounds adjusted for any reduction factors
$\ddot{\theta}$ = angular acceleration of cam
T_{motor} = motor torque as a function of rpm
T_{cam} = torque due to the loads on the cam, including friction and bolt inertia loads as a function of the cam curve
T_{frict} = torque due to gear friction
T_{belt} = torque due to weight of rounds in belt being moved

Solving for the angular acceleration, $\ddot{\theta}$, yields

$$\ddot{\theta} = \frac{T_{motor} - T_{cam} - T_{frict} - T_{belt}}{I_{cam} + I_{feed} + I_{gears}} \qquad \text{(IB)}$$

NUMERICAL INTEGRATION METHOD

The integration technique employed by the program is Adams four-point method. The integration formula is as follows:

$$y_{n+1} = y_n + \frac{\Delta t}{24}\left(55\,\dot{y}_n - 59\,\dot{y}_{n-1} + 37\,\dot{y}_{n-2} - 9\,\dot{y}_{n-3}\right) \qquad \text{(II)}$$

In order to obtain $\dot{y}_{n-1}$, $\dot{y}_{n-2}$, and $\dot{y}_{n-3}$ to start the integration process, a Taylor series expansion is performed as follows:

$$\left.\begin{cases}
y_1^{(1)} = y_0 + \Delta t y_0' & (1) \\
y_1^{(2)} = y_0 + \frac{\Delta t}{2}\left(y_1^{(1)'} + y_0'\right) & (2) \\
y_1^{(3)} = y_0 + \frac{\Delta t}{6}\left(2y_1^{(2)'} + y_1^{(1)'} + 3y_0'\right) & (3) \\
y_2^{(1)} = y_1^{(3)} + \frac{\Delta t}{2}\left(3y_1^{(3)'} - y_0'\right) & (4) \\
y_2^{(2)} = y_1^{(3)} + \frac{\Delta t}{12}\left(5y_2^{(1)'} + 8y_1^{(3)'} - y_0'\right) & (5) \\
y_3^{(1)} = y_2^{(2)} + \frac{\Delta t}{12}\left(23y_2^{(2)'} - 16y_1^{(3)'} + 5y_0'\right) & (6) \\
y_3^{(2)} = y_2^{(2)} + \frac{\Delta t}{24}\left(9y_3^{(1)'} + 19y_2^{(2)'} - 5y_1^{(3)'} + y_0'\right) & (7)
\end{cases}\right\} \quad \text{(III)}$$

Equations (3), (5), and (7) are then used as solutions for the first three points.

The math model uses the following sequence in integrating:

$$\ddot{\theta}_{n+1} = \frac{\Sigma T}{I} \quad \text{(Equation of motion, IB)}$$

$$\text{TIME}_{n+1} = \text{TIME}_n + \Delta\,\text{TIME}$$

$$\theta_{n+1} = \theta_n + \int \dot{\theta}_n \, dt \quad \text{(Equation II above)}$$

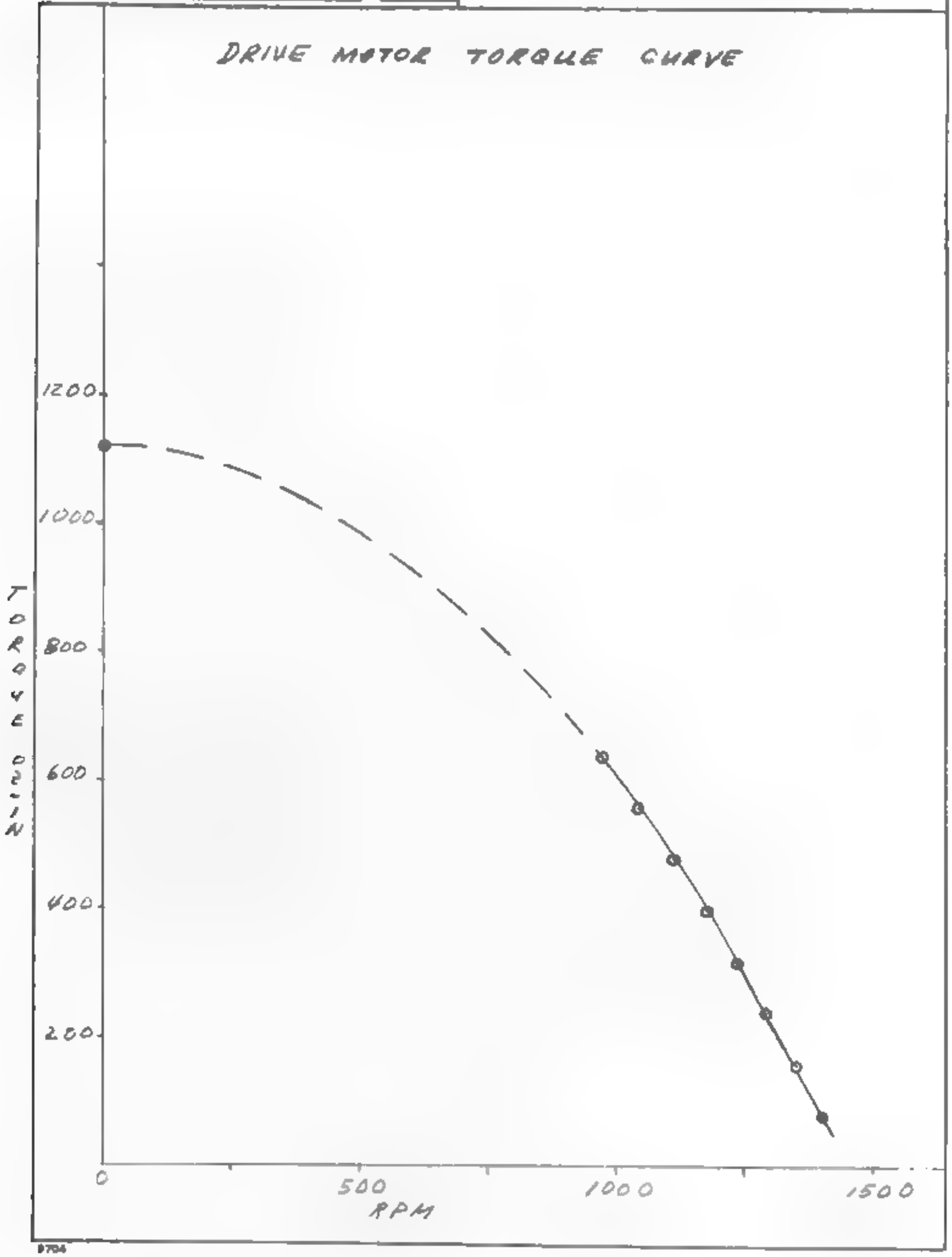
$$\dot{\theta}_{n+1} = \dot{\theta}_n + \int \ddot{\theta}_{n+1} \, dt \quad \text{(Equation II above)}$$

MOTOR CHARACTERISTIC CURVE

The math model utilizes a torque versus rpm curve to simulate the drive motor. Upon attaining steady-state rpm, the motor is 'shut off' and the program simply calculates the torque that would be required of the motor to keep the system running at steady-state rpm. An exception is made at the point where the carrier picks up the bolt. The resulting velocity after impact is decreased substantially so that the motor must operate at full power in order to restore the system to steady-state rpm.

HUGHES TOOL COMPANY-AIRCRAFT DIVISION

ANALYSIS EPAM MATH MODEL | MODEL | REPORT NO. | PAGE
PREPARED BY D.A DEC 7, 1970
CHECKED BY
EPAM



9704

CAM CURVE

The cam drive used in the math model is a modified-trapezoidal type, with 41.25 degree constant velocity portions. The constant acceleration portion (parabolic) has the following characteristics

$$X = A_{cam} Y^2$$

where $A_{cam} = 1.6609/\text{ft}$ = the curve constant.

The cycloidal portion of the curve is defined by a quarter wave with the peak point equal to A_{cam}. A layout of the curve is shown on page 21 of this section.

CAM FORCES

The torque on the cam (TCAM) is obtained as follows:

$$T_{cam} = N_t R_c$$

where

N_t = the transverse component of the cam normal force

R_c = the cam radius

Also,

$$N_t = N \sin \alpha + \mu_r N \cos \alpha$$

where

N and α are as defined in the free-body diagram of page 23, and μ_r N is the resistance induced by rolling friction

$$N_a = N \cos \alpha - \mu_r N \sin \alpha$$

The track reactions due to rotational forces are found by balancing moments in the plane perpendicular to the bolt-carrier axis.

$$c R_r = d \left(F - F_r\right)$$

$$R_r = \left(\frac{d}{c}\right) \left(F - F_r\right)$$

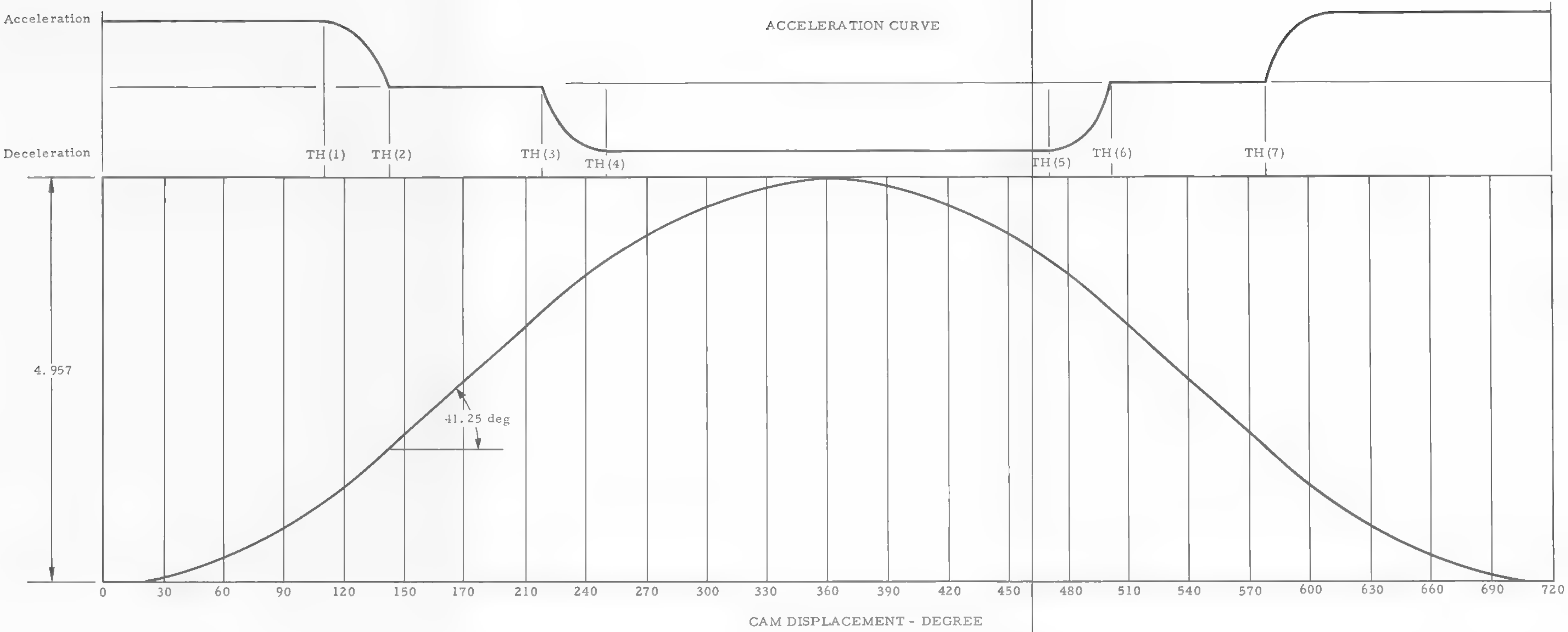


Figure 7. Cam Characteristics

The track reactions due to tipping forces are found by balancing moments in the vertical plane parallel to the bolt-carrier axis.

$$b R_t = d N_a$$

$$R_t = \left(\frac{d}{b} \right) N_a$$

The frictional resistance due to track reactions is

$$R_{fr} = \pm 2 \mu_t \left(R_r + R_t \right)$$

R_{fr} has the same algebraic sign as $\dot{Y}$.

The normal force on the cam roller is found by balancing the axial forces, thus $\Sigma F_Y = 0$

$$F_a + \mu_t N_t - N_a + R_{fr} = 0$$

Substituting all the expressions containing N in the above equation yields

$$N = \left| F_a \Big/ \left\{ \left[\mu_r + \mu_t \left(1 + \frac{e}{b} \right) + 2 \frac{d}{c} \mu_t - 2 \frac{d}{b} \mu_r \mu_t \right] \sin \alpha \right.\right.$$
$$\left.\left. + \left[\mu_r \mu_t \left(1 + \frac{e}{b} \right) + 2 \frac{d}{c} \mu_r \mu_t + 2 \frac{d}{b} \mu_t - 1.0 \right] \cos \alpha \right\} \right|$$

The corresponding equation for the deceleration phase becomes

$$N = \left| F_a \Big/ \left\{ \left[\mu_r \mu_t \left(1 + \frac{e}{b} \right) + 2 \frac{d}{c} \mu_r \mu_t - 2 \frac{d}{b} \mu_t - 1.0 \right] \cos \alpha \right.\right.$$
$$\left.\left. - \left[\mu_r + \mu_t \left(1 + \frac{e}{b} \right) + 2 \frac{d}{b} \mu_r \mu_t + 2 \frac{d}{c} \mu_t \right] \sin \alpha \right\} \right|$$

Letting

$$C_1 = \mu_r + \mu_t \left(1 + \frac{e}{b} \right) + 2 \frac{d}{c} \mu_t - 2 \frac{d}{b} \mu_r \mu_t$$

$$C_2 = \mu_r \mu_t \left(1 + \frac{e}{b} \right) + 2 \frac{d}{c} \mu_r \mu_t + 2 \frac{d}{b} \mu_t - 1$$

$$C_3 = - \left[\mu_r + \mu_t \left(1 + \frac{e}{b} \right) + 2 \frac{d}{c} \mu_t + 2 \frac{d}{b} \mu_r \mu_t \right]$$

$$C_4 = \mu_r \mu_t \left(1 + \frac{e}{b} \right) + 2 \frac{d}{c} \mu_r \mu_t - 2 \frac{d}{b} \mu_t - 1$$

$$F_a = M \ddot{Y} + K_s Y_t + K_{pin} Y_{pin} + F_{strip}$$

yields

$$N = F_N = -\left(M\ddot{Y} + K_s Y_t + K_{pin} Y_{pin} + F_{strip} \right) \Big/ \left(C_1 \sin\alpha + C_2 \cos\alpha \right)$$

(The negative sign is added here to cancel the sign of C_2, which is negative)

For the deceleration portions of the cam curve,

$$N = F_N = -\left(M\ddot{Y} - F_{strip} \right) \Big/ \left(C_3 \sin\alpha + C_4 \cos\alpha \right)$$

where

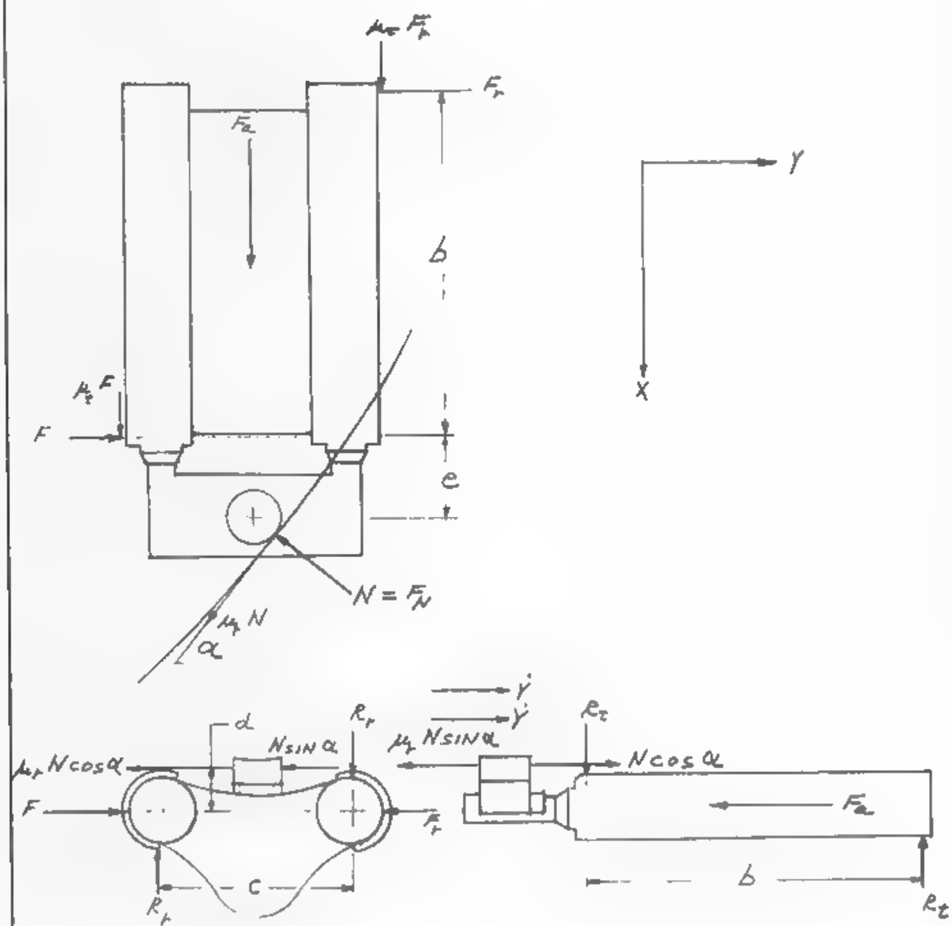
M	= mass of bolt-carrier combination
$\ddot{Y}$	= axial acceleration of M
K_S	= combined spring rate of carrier spring pack and cartridge (used only when simulating the jamming of a round in the chamber)
Y_t	= the deflection associated with K_S
K_{pin}	= spring rate of firing pin
Y_{pin}	= the deflection of the firing pin spring
F_{strip}	= the average load required to strip a round from the link = 6.8 lb (test data)

It should be noted that the terms comprising F_a above act only during those portions of the cam curve as defined by the corresponding input cam positions (see input data section).

HUGHES TOOL COMPANY-AIRCRAFT DIVISION

ANALYSIS: EPAM
MODEL
REPORT NO. [redacted]
PREPARED BY: D. A 2-12-71
CHECKED BY

LOADING DIAGRAM OF BOLT-CARRIER UNIT DURING CAM ACCELERATION



BOLT-CARRIER IMPACT LOADS

At the indicated cam curve position, THIMP & THREL (input data, items 21 and 22), the carrier releases the bolt (THREL) and picks it up again during its rearward motion (THIMP), at which time a momentum exchange takes place between the moving carrier and the stationary bolt.

Three simplifying assumptions will be made at this point. First, the bolt and carrier will be assumed to be moving at the same velocity after the initial impact, thus ignoring any subsequent minor collisions that take place before the two are locked together. Second, the velocity of the system (bolt, carrier, plus cam and gears) after impact will be given by that of the first mass (carrier, cam, and gears) after impact. Finally, the collision is assumed to take place during the rearward acceleration portion of the parabolic curve.

The momentum of the first mass (carrier, cam, and gears) before impact is given by

$$\text{Momentum} = M_c V_c + \frac{I_{equiv} \dot{\theta} \sin\alpha \cos\alpha}{R_c}$$

where

M_c = mass of the carrier
R_c = radius of cam
V_c = axial velocity of the carrier
I_{equiv} = combined moment of inertia of the cam and gears
α = angle of cam slope
$\dot{\theta}$ = angular velocity of the cam

For the parabolic portion of the curve, the carrier velocity and $\dot{\theta}$ are related as follows:

$$V_c = \frac{dY}{dt} = 2 A_{cam} R_c^2 \; \theta \frac{d\theta}{dt}$$

where

A_{cam} = the parabolic curve constant
θ = the angular displacement along the parabolic portion of the curve

Substituting yields

$$\text{Momentum} = \left(M_c + \frac{I_{equiv} \sin\alpha \cos\alpha}{2 A_{cam} R_c^3 \theta} \right) V_c$$

The velocity of the system after impact, V_c', is then

$$V_c' = \frac{\left(M_c + \frac{I_{equiv} \sin\alpha \cos\alpha}{2 A_{cam} R_c^3 \theta}\right) V_c - C_r M_B \left(V_c - V_B\right)}{M_c + \frac{I_{equiv} \sin\alpha \cos\alpha}{2 A_{cam} R_c^3 \theta} + M_B}$$

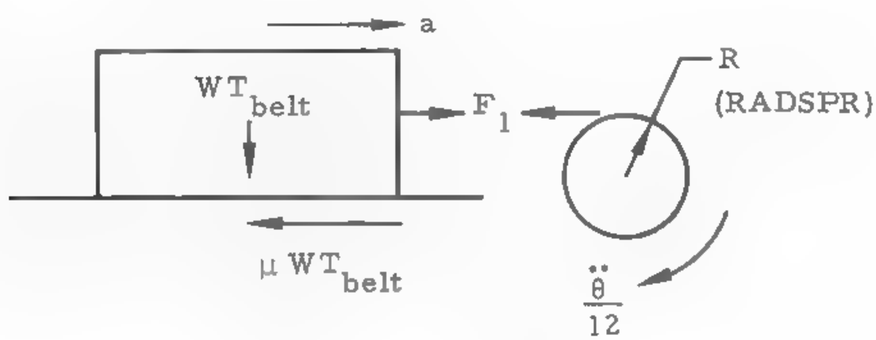
where

C_r = the coefficient of restitution for the impacting masses

M_B = the mass of the bolt

V_B = the velocity of the bolt before impact $\left(V_B = 0\right)$

BELT TORQUE



From the free-body diagram, the force, F_1, is given as

$$F_1 = \mu\, WT_{belt} + \frac{WT_{belt}}{G}\, a$$

$$F_1 = WT_{belt}\left(\mu + \frac{R\ddot{\theta}}{12\, G}\right)$$

where

μ = 1.8 = load factor for an ammunition belt in a horizontal chute (Reference 2)

WT_{belt} = weight of the ammunition belt

G = 32.17 ft per sec^2 = gravitational constant

a $= \frac{R\ddot{\theta}}{12}$ = the acceleration of the belt

$\ddot{\theta}$ = the angular acceleration of the cam (since the feed sprocket rotates at one-twelfth the speed of the cam, $\ddot{\theta}/12$ is the angular acceleration of the feed sprocket)

Hence, the torque due to belt loads is

$$T_{belt} = R F_1 = R W T_{belt} \left(\mu G_{field} + \frac{R\ddot{\theta}}{12 G} \right)$$

where

G_{field} = the G-loading under which the belt will be moving.

INPUT DATA

The following is a Fortran name list and description of all the inputs in the order they should read.

Data Location	Fortran Name	Description	Units
1	ACAM	Cam curve constant	1/Ft
2	GFIELD	Gravitational field	G's
3	RADIUS	Mean cam radius	Ft
4	RADSPR	Radius of feed sprocket	Ft
5	CR	Coefficient of restitution for bolt-carrier impact	None
6	OMEGA	Steady state angular velocity of cam	Rad/Sec
7	MC	Mass of carrier	Slugs
8	MB	Mass of bolt	Slugs
9	WTBELT	Weight of ammunition belt	Lb
10	LCAM	Axial length of cam	Ft
11	IGEAR	Moments of inertia of all gears normalized to the angular velocity of cam	$Ft\text{-}Lb\text{-}Sec^2$
12	IFEED	Moment of inertia of feed sprocket(s) normalized to the angular velocity of cam	$Ft\text{-}Lb\text{-}Sec^2$
13	ICAM	Moment of inertia of cam	$Ft\text{-}Lb\text{-}Sec^2$
14	KP	Spring rate of carrier spring rack	Lb/Ft
15	KT	Damping coefficient for gears	$\frac{Lb\text{-}Ft}{Rad/Sec}$

Data Location	Fortran Name	Description	Units
16	KR	Spring rate of rounds	Lb/Ft
17	KPIN	Spring rate of firing pin mechanism	Lb/Ft
18	YINIT	Bolt position when jamming begins	Ft
19	YPRE	Preload of carrier spring pack	
20	ASIN	Length of cycloidal portions of cam	Rad
		(NOTE: All angular cam positions are referenced with respect to the rearmost follower position)	
21	THIMP	Angular position of cam when carrier impacts bolt	Rad
22	THREL	Angular position of cam when carrier releases bolt	Rad
23	THTCRU	Angular position of cam when jamming begins	Rad
24	THRAM(1)	Angular position of cam when cartridge ramming begins	Rad
25	THRAM(2)	Angular position of cam corresponding to end of peak stripping load	Rad
26	THRAM(3)	Angular position of cam when cartridge ramming terminates	Rad
27	THPIN(1)	Angular position of cam when contact is first made with firing pin spring during forward motion of bolt	Rad
28	THPIN(2)	Angular position of cam during forward motion where firing pin becomes fully cocked	Rad

Data Location	Fortran Name	Description	Units
29	THPIN(3)	Angular position of cam where bolt locking terminates and firing pin is released	Rad
30		NOT USED	
31	TH(1)	Angular position of cam when first parabolic portion of curve terminates	Rad
32	TH(2)	Angular position of cam when first cycloidal portion of curve terminates	Rad
33	TH(3)	Angular position of cam where constant velocity portion of curve terminates	Rad
34	TH(4)	Angular position of cam where second parabolic portion of curve terminates	Rad
35	TH(5)	Same as TH(1) + 360° (Set Internally)	Rad
36	TH(6)	Same as TH(2) + 360° (Set Internally)	Rad
37	TH(7)	Same as TH(3) + 360° (Set Internally)	Rad
38	FSTRP1	Initial peak stripping load	Lb
39	FSTRP2	Average stripping load excluding initial peak load	Lb
40	FLOCK1	Average load during bolt unlocking phase	Lb
41	UR	Coefficient of rolling friction for cam follower	None
42	UT	Coefficient of sliding friction for carrier track	None

Data Location	Fortran Name	Description	Units
43	BB	Moment arm of tipping track reactions of carrier	In.
44	CB	Moment arm of rotational track reactions	In.
45	CB	Distance from bolt-carrier center of gravity to cam roller surface	In.
46	EB	Axial distance of carrier between rearmost edge of track and contact point on roller surface	In.
47	RPMT(1)	First value of rpm for the motor rpm versus torque table in ascending rpm order	RPM
66	RPMT(20)	Last value of rpm for table	RPM
67	TTAB(1)	First value of torque for rpm versus torque table	Oz-In.
86	TTAB(20)	Last value of torque for rpm versus torque table	Oz-In.

The following free-format input data precedes data items 1 through 84:

None	ND	Total number of data items (1 through 84) to be read in if different from built-in block data values	None
None	DT	Integration step size	Sec
None	X	Initial angular position of cam (0 is rearmost dead center)	Rad
None	DX	Initial angular velocity of cam	Rad
None	TFINAL	Final program time	Sec
None	KPRINT	Print interval	None
None	CYCLES	Number of firing cycles to be run after attaining steady-state RPM (OMEGA)	None

OUTPUT DATA

Fortran Name	Description	Units
I	Counter, for internal program bookkeeping only	None
TIME	Time from application of power to the cam	Sec
THETA	Total angular displacement of cam	Deg
DTHETA	Cam angular velocity	Rad/Sec
DDTHETA	Cam angular acceleration	Rad/Sec^2
TORQUE	Motor torque available during start-up, required during steady state	Lb-Ft
POWER	Motor power available during start-up, required during steady state	HP
RPM	Cam angular velocity	RPM
FN	Normal force between cam and cam follower	Lb
TBELT	Torque on system due to ammunition belt loads	Lb-Ft
DDY	Axial acceleration of the bolt-carrier system	Ft/Sec^2
ALPHA	Time dependent value of the cam curve slope	Rad
THTA	Angular distance measured from the origin of the parabolic portions of the cam curve	Rad

EPAM MATH MODEL OUTPUT

```
>RUN
0,.001,.0,.0,.4,5,2
```

INITIAL CONDITIONS

TIME	STEP SIZE	FINAL TIME	PRINT INTERVAL
0.000	.0010	.4000	5

MOMENTS OF INERTIA CAM FT-LB-SEC2	GEARS	FEED SYS	CAM RADIUS FT	BOLT MASS SLUGS
.0008700	.0000277	.0000017	.11717	.02969

I	TIME SEC	THETA DEG	DTHETA RAD/SEC	DDTHETA RAD/SEC2	TORQUE LB-FT	POWER HP	RPM	BOLT IN
1	0.000	0.00	0.00	0.0	5.833	0.000	0.0	0.000
2	.004	2.90	25.18	6153.4	5.666	.259	240.4	.001
3	.009	14.35	54.11	5360.1	5.082	.500	516.7	.017
4	.014	33.42	78.04	4127.8	4.317	.612	745.2	.093
5	.019	58.39	95.07	2696.8	3.623	.626	907.8	.284
6	.024	87.24	105.16	1359.6	3.139	.600	1004.2	.634
7	.029	118.07	109.38	579.8	2.878	.572	1044.5	1.162
8	.034	150.19	116.12	1629.9	2.520	.532	1108.8	1.637
9	.039	184.55	123.41	1374.5	2.060	.462	1178.5	2.577
10	.044	220.23	127.33	810.7	1.810	.419	1215.9	3.329
11	.049	258.11	131.55	2474.9	1.510	.361	1256.2	4.092
12	.054	297.69	143.02	1187.9	.702	.183	1365.7	4.633
13	.059	339.40	146.79	381.9	.405	.108	1401.8	4.922
14	.064	381.55	146.94	-307.7	.395	.105	1403.2	4.918
15	.069	423.30	144.13	-769.6	.614	.161	1376.3	4.623
16	.076	469.72	101.90	2265.4	3.342	.619	973.1	3.954
17	.081	499.78	108.50	1942.8	2.926	.577	1036.1	3.328
18	.086	532.20	117.37	1643.2	2.445	.522	1120.8	2.646
19	.091	566.91	124.71	1293.1	1.978	.448	1190.8	1.899
20	.096	603.77	134.24	2489.2	1.297	.317	1281.9	1.126
21	.101	643.87	144.85	1666.2	.556	.147	1383.2	.483
22	.106	686.30	150.43	546.1	.163	.045	1436.5	.095
23	.111	9.51	150.29	-578.1	.172	.047	1435.2	.008
24	.116	51.94	145.27	-1326.7	.523	.138	1387.2	.225
25	.121	92.53	137.92	-1567.8	1.053	.264	1317.0	.714
26	.126	130.98	131.69	-87.4	1.499	.359	1257.6	1.430
27	.131	169.21	135.34	738.7	1.217	.300	1292.4	2.246
28	.136	208.30	136.34	117.8	1.154	.286	1301.9	3.088
29	.141	247.87	142.74	1756.3	.725	.188	1363.0	3.909
30	.146	289.79	149.05	846.3	.255	.069	1423.3	4.546
31	.151	332.93	151.45	143.4	.095	.026	1446.3	4.896
32	.156	376.26	150.52	-501.2	.158	.043	1437.3	4.935
33	.161	418.90	146.78	-955.2	.405	.108	1401.7	4.668
34	.168	466.23	104.61	1931.7	3.174	.604	998.9	4.016
35	.173	496.89	109.89	1652.3	2.851	.570	1049.4	3.395
36	.178	529.74	118.31	1632.0	2.385	.513	1129.7	2.699
37	.183	564.66	125.68	1237.6	1.916	.438	1200.1	1.948
38	.188	601.78	134.13	2479.3	1.306	.318	1280.8	1.165
39	.193	641.85	145.08	1679.3	.538	.142	1385.4	.509
40	.198	684.36	150.76	568.9	.148	.039	1439.6	.106
41	.203	7.68	150.76	-562.6	.141	.039	1439.7	.005
42	.208	50.25	145.76	-1333.1	.484	.128	1391.9	.210
43	.213	90.98	138.37	-1575.7	1.025	.258	1321.3	.690
44	.218	129.52	131.84	-261.7	1.488	.357	1259.0	1.398
45	.223	167.69	135.54	685.7	1.205	.297	1294.3	2.214
45	.227	199.02	135.86	360.4	1.184	.292	1297.4	2.888

AVERAGE TRANSIENT POWER = .54639996 HP
AVERAGE STEADY STATE POWER = .25101808 HP

TIME SEC	FN LB	TBELT LB-FT	DDY FT/SEC2	THTA RAD	ALPHA DEG	FCAM	TFRICT LB-FT
0.000	.000E+01	.000E+01	.000E+01	.000E+01	.000E+01	.000E+01	.000E+01
.004	.135E+01	.937E-01	.433E+02	.507E-01	.113E+01	.112E+00	.252E-01
.009	.629E+01	.899E-01	.197E+03	.251E+00	.557E+01	.100E+01	.541E-01
.014	.134E+02	.838E-01	.395E+03	.583E+00	.128E+02	.378E+01	.780E-01
.019	.205E+02	.761E-01	.551E+03	.102E+01	.216E+02	.876E+01	.951E-01
.024	.264E+02	.687E-01	.616E+03	.152E+01	.307E+02	.149E+02	.105E+00
.029	.278E+02	.630E-01	.556E+03	.206E+01	.384E+02	.186E+02	.109E+00
.034	.105E+02	.702E-01	.195E+03	.262E+01	.413E+02	.741E+01	.116E+00
.039	.765E+01	.675E-01	.142E+03	.322E+01	.413E+02	.540E+01	.123E+00
.044	.108E+02	.629E-01	-.266E+02	.244E+01	.410E+02	.761E+01	.127E+00
.049	.149E+02	.590E-01	-.805E+03	.178E+01	.347E+02	-.773E+01	.132E+00
.054	.148E+02	.675E-01	-.864E+03	.109E+01	.229E+02	-.492E+01	.143E+00
.059	.166E+02	.629E-01	-.974E+03	.360E+00	.797E+01	-.127E+01	.147E+00
.064	.192E+02	.590E-01	-.982E+03	.376E+00	.833E+01	.397E+01	.147E+00
.069	.208E+02	.562E-01	-.912E+03	.110E+01	.233E+02	.944E+01	.144E+00
.076	.152E+02	.502E-01	-.315E+03	.191E+01	.367E+02	.983E+01	.102E+00
.081	.122E+02	.690E-01	-.227E+03	.244E+01	.410E+02	.855E+01	.108E+00
.086	.942E+01	.692E-01	-.175E+03	.301E+01	.413E+02	.666E+01	.117E+00
.091	.752E+01	.673E-01	-.140E+03	.361E+01	.413E+02	.531E+01	.125E+00
.096	.173E+02	.731E-01	-.562E+03	.203E+01	.380E+02	-.981E+01	.134E+00
.101	.245E+02	.701E-01	-.843E+03	.133E+01	.273E+02	-.988E+01	.145E+00
.106	.286E+02	.642E-01	-.101E+04	.588E+00	.129E+02	-.463E+01	.150E+00
.111	.324E+02	.580E-01	.103E+04	.166E+00	.370E+01	.413E+01	.150E+00
.116	.330E+02	.533E-01	.911E+03	.906E+00	.194E+02	.130E+02	.145E+00
.121	.331E+02	.517E-01	.754E+03	.162E+01	.322E+02	.194E+02	.138E+00
.126	.171E+02	.555E-01	.324E+03	.229E+01	.404E+02	.119E+02	.132E+00
.131	.427E+01	.642E-01	.793E+02	.295E+01	.413E+02	.302E+01	.135E+00
.136	.103E+02	.580E-01	-.375E+02	.364E+01	.413E+02	.728E+01	.136E+00
.141	.165E+02	.696E-01	-.766E+03	.196E+01	.371E+02	-.911E+01	.143E+00
.146	.165E+02	.659E-01	-.952E+03	.123E+01	.255E+02	-.615E+01	.149E+00
.151	.177E+02	.615E-01	-.104E+04	.473E+00	.104E+02	-.210E+01	.151E+00
.156	.198E+02	.579E-01	-.103E+04	.284E+00	.630E+01	.341E+01	.151E+00
.161	.211E+02	.552E-01	-.941E+03	.103E+01	.218E+02	.906E+01	.147E+00
.168	.172E+02	.513E-01	-.363E+03	.185E+01	.358E+02	.109E+02	.105E+00
.173	.144E+02	.672E-01	-.271E+03	.239E+01	.409E+02	.101E+02	.110E+00
.178	.882E+01	.686E-01	-.164E+03	.296E+01	.413E+02	.623E+01	.118E+00
.183	.737E+01	.672E-01	-.137E+03	.357E+01	.413E+02	.521E+01	.126E+00
.188	.169E+02	.722E-01	-.545E+03	.206E+01	.384E+02	-.965E+01	.134E+00
.193	.245E+02	.702E-01	-.842E+03	.136E+00	.280E+02	-.101E+02	.145E+00
.198	.287E+02	.643E-01	-.101E+04	.622E+00	.136E+02	-.499E+01	.151E+00
.203	.325E+02	.582E-01	.103E+04	.134E+00	.299E+01	.374E+01	.151E+00
.208	.331E+02	.533E-01	.920E+03	.877E+00	.188E+02	.127E+02	.146E+00
.213	.332E+02	.596E-01	.761E+03	.159E+01	.317E+02	.192E+02	.138E+00
.218	.189E+02	.548E-01	.360E+03	.226E+01	.402E+02	.131E+02	.132E+00
.227	.807E+01	.558E-01	-.791E+02	.347E+01	.413E+02	.570E+01	.136E+00

EPAM PROGRAM LISTING

```
1 C:     EPAM MATH MODEL
2 C:     VERSION OF MAY 3, 1971


3        COMMON/FORCES/KI,PI,PI2,IEQUIV,TFRICT,MASS,RPM,POWER,DDY,
         G,FN,TBELT,THTA,ALPHA,TORQUE,TCAM,C1,C2,C3,C4,KS,YT,YBOLT,
         NCYCLE,THETA1,IMTEST,IPIN
4        COMMON/DATA1/DATA(86)
5        DIMENSION TSAVE(250),FNS(250),TBELTS(250),DDYS(250),THTAS(250),
         ALPHAS(250),FCAMS(250),TFRICS(250),TH(10),RPMT(20),TTAB(20),
         THRAM(3),THPIN(4)
6        REAL IEQUIV,IGEAR,IFEED,ICAM,KT,MASS,KS,KP,KR,KPIN,MB,MC,LCAM
7        DOUBLE PRECISION DT
8        EQUIVALENCE          (DATA(1) ,ACAM  ), (DATA(2) ,GFIELD),
         (DATA(3) ,RADIUS), (DATA(4) ,RADSPR), (DATA(5) ,CR    ),
         (DATA(6) ,OMEGA ), (DATA(7) ,MC    ), (DATA(8) ,MB    ),
         (DATA(9) ,WTBELT), (DATA(10),LCAM  )
9        EQUIVALENCE          (DATA(11),IGEAR ), (DATA(12),IFEED ),
         (DATA(13),ICAM  ), (DATA(14),KP    ), (DATA(15),KT    ),
         (DATA(16),KR   .), (DATA(17),KPIN  ), (DATA(18),YINIT ),
         (DATA(19),YFRE  ), (DATA(20),ASIN  )
10       EQUIVALENCE          (DATA(21),THIMP ), (DATA(22),THREL ),
         (DATA(23),THTCRU), (DATA(24),THRAM(1)),(DATA(27),THPIN(1)),
         (DATA(31),TH(1) ), (DATA(38),FSTRP1), (DATA(39),FSTRP2),
         (DATA(40),FLOCK1)
11       EQUIVALENCE          (DATA(41),UR    ), (DATA(42),UT    ),
         (DATA(43),BB    ), (DATA(44),CB    ), (DATA(45),DB    ),
         (DATA(46),EB    ), (DATA(47),RPMT(1)),(DATA(67),TTAB(1))
12 C:
13       PI=3.14159; PI2=2.*PI; G=32.17
14 C:     READ INPUT DATA
15     5 KNO=0
16       ACCEPT ND,DT,X,DX,TFINAL,KPRINT,CYCLES
17     6 KNO=KNO+1
18       IF(KNO.LE.ND)(ACCEPT I,DATA(I); GO TO 6)
19       KS=1.0/(1./KP+1./KR)
20       IEQUIV=ICAM+IGEAR+IFEED
21       MASS=MB+MC
22       TH(5)=PI2+TH(1); TH(6)=PI2+TH(2); TH(7)=PI2+TH(3)
23 C:     CALCULATE COEFFICIENTS FOR NORMAL FORCE EQUATION
24       C1=UR+UT*(1.+EB/BB)+2.*DB/CB*UT-2.*DB/BB*UR*UT
25       C2=UR*UT*(1.+EB/BB)+2.*DB/CB*UT*UR+2.*DB/BB*UT-1.0
26       C3=-(UR+UT*(1.+EB/BB)+2.*DB/CB*UT+2.*DB/BB*UR*UT)
27       C4=UR*UT*(1.+EB/BB)+2.*DB/CB*UT*UR-2.*DB/BB*UT-1.0
28 C:     CALCULATE IMPACT FACTOR FOR BOLT-CARRIER IMPACT
29       DY=2.*ACAM*RADIUS*(THIMP-PI2)
30       ALPHA=ATAN(DY)
31       REFEC=DY*RADIUS**2
32       VIMPAC=((MC+IEQUIV*SIN(ALPHA)*COS(ALPHA)/REFEC)-CR*MB)
           /(MC+IEQUIV*SIN(ALPHA)*COS(ALPHA)/REFEC+MB)
33       T=0.; DDX=0.0; NOUT=1
34       KI=0; IN=0; K=1; KTEST=0; LTEST=0; IMTEST=1; KSTEDY=0
35       FN=0.0; POWER=0.0; FMUX=0.0; FOLD=0.0; IPIN=0
36       AP=0.0 ; APT=0.0; XOLD=0.0; XOLDT=0.0; YT=0.0
37 C:     WRITE HEADING AND INITIAL CONDITIONS
38       WRITE(1,30) T,DT,TFINAL,KPRINT
39       WRITE(1,60) ICAM,IGEAR,IFEED,RADIUS,MASS
40       WRITE(1,35)K,T,X,DX,DDX,TTAB(1)/192.,POWER,RPM,YBOLT*12.
41 C:     BEGIN INTEGRATION CYCLE
42    10 IF(M.EQ.1.OR.M.EQ.2.OR.M.EQ.4.OR.M.EQ.6) GO TO 11
43       DAP=(POLD+POWER)*(X-XOLDT)/2.; APT=APT+DAP;
         XOLDT=X; POLD=POWER
44    11 CALL ACCEL(DDX,T,X,DX,IN,FCAM)
45       IF(M.EQ.1.OR.M.EQ.2.OR.M.EQ.4.OR.M.EQ.6) GO TO 24
46       KTEST=KTEST+1
47       POWER=TORQUE*DX/550.
48       IF(X.LT.2.*CYCLES*PI2+XOLDT) GO TO 14
49       PWPS=AP/(X-XOLDT)
50       NOUT=2
51       GO TO 16
```

```
   14 IF(KTEST .NE. KPRINT)GO TO 24
      KTEST=0; K=K+1
   16 WRITE(1,40)K,T,THETA1*57.29578,DX,DDX,TORQUE,POWER,RPM,YBOLT*12.
      TSAVE(K)=T; FNS(K)=FN; TBELTS(K)=TBELT; DDYS(K)=DDY
      ALPHAS(K)=ALPHA*57.29578; THTAS(K)=THTA; FCAMS(K)=FCAM
      TFRICS(K)=TFRI..
      IF(T.GT.TFINAL) GO TO 20
      IF(X.GT.THTCRU.AND.RPM.LT.2.) GO TO 20
      GO TO (24,20),NOUT
C:     AT 20, TERMINATE CASE AND GO TO 5 (NEXT CASE)
   20 PWPT=ART/XOLDT
      DISPLAY"  "
      DISPLAY"   AVERAGE TRANSIENT POWER =",PWRT," HP"
      DISPLAY"   AVERAGE STEADY STATE POWER =",PWRS," HP"
      DISPLAY           "  "
      DISPLAY" TIME      FN      TBELT      DDY      THTA       ALPHA  ",
      "FCAM    TFRICT"
      DISPLAY" SEC       LB       LB-FT    FT/SEC2    RAD         DEG  ",
      " LB       LB-FT"
      DO 22 IR=1,K
   22 WRITE(1,50) TSAVE(IR),FNS(IR),TBELTS(IR),DDYS(IR),THTAS(IR),
        ALPHAS(IR),FCAMS(IR),TFRICS(IR)
      GO TO 5
C:     AT 24 THRU 30 UPDATE TIME, DISPLACEMENT AND VELOCITY,
      THEN START NEXT INTEGRATION CYCLE
   24 IF(THETA1.LT.THIMP .OR. IMTEST.EQ.1) GO TO 25
      IMTEST=1
      IN=0
      DX=VIMPAC*DX
      KTEST=0
   25 ASSIGN 10 TO NL
      IF(DX.LT.OMEGA.O: .KSTEDY.EQ.1) GO TO 26
      KSTEDY=1
      XOLD=XOLDT
   26 IF(KSTEDY.NE.1) GO TO 28
      ASSIGN 11 TO NL
      IF(M.EQ.1.OR.M.EQ. 2.OR.M.EQ.4.OR.M.EQ.6) GO TO 28
      DAP=(POLD+POWER)*(X-XOLD)/2.
      XOLD=X
      [illegible]
      POLD=POWER
   28 T=AINDV(T,DT,M,IN,NC)
      X=DINV(X,DX,DT,M,NC)
      DX=DINV(DX,DDX,DT,M,NC)
      GO TO NL,(10,11)
   30 FORMAT(//,25X,19HINITIAL CONDITIONS /4X,5H TIME13X,9HSTEP SIZE
        8X,10HFINAL TIME,6X14HPRINT INTERVAL/F10.3,2F18.4,14X,I3)
   35 FORMAT(/2X,1H1,3X,22HTIME     THETA    DTHETA ,2X,7HDDTHETA,
      3X,31HTORQUE     POWER     RPM       BOLT  /6X,12HSEC       DEG
      ,3X,33HRAD/SEC   RAD/SEC2   LB-FT      HP  ,14X,2HIN/
      I3,F7.3,2F9.2,F9.1,2F9.3,F8.1,F8.3)
   40 FORMAT(I3,F7.3,2F9.2,F9.1,2F9.3,F8.1,F8.3)
   50 FORMAT(F6.3,7E9.3)
   60 FORMAT(/10X,18HMOMENTS OF INERTIA ,9X,3HCAM 6X4HBOLT/
      5X,3HCAM6X 5HGEARS 2X 9HFEED SYS 6X 6HRADIUS 4X 4HMASS/
      12X,10HFT-LB-SEC2 16X 2HFT 6X 5HSLUGS /
      2X,3F9.7,4X 2F9.5)
      END
         SUBROUTINE ACCEL(DDTHET,T,THETA,DTHETA,IN,FCAM)

       COMMON/FORCES/KI,PI,PI2,IEQUIV,TFRICT,MASS,RPM,POWER,DDY,
      G,FN,TBELT,THTA,ALPHA,TORQUE,TCAM,C1,C2,C3,C4,KS,YT,YBOLT,
      NCYCLE,THETA1,IMTEST,IPIN
       COMMON/DATA1/DATA(86)
       DIMENSION TH(10), RPMT(20), TTAB(20),THPAM(3),THPIN(4)
       REAL IEQUIV,IGEAR,IFEED,ICAM,KT,MASS,KS,KP,KR,KPIN,MB,MC,LCAM
       EQUIVALENCE         (DATA(1) ,ACAM  ), (DATA(2) ,GFIELD),
      (DATA(3) ,RADIUS), (DATA(4) ,RADSPR), (DATA(5) ,CR    ),
      (DATA(6) ,OMEGA ), (DATA(7) ,MC     ), (DATA(8) ,MB     ),
      (DATA(9) ,WTBELT), (DATA(10),LCAM   )
```

```
      EQUIVALENCE         (DATA(11),IGEAR ), (DATA(12),IFEED ),
     (DATA(13),ICAM  ), (DATA(14),KP    ), (DATA(15),KT    ),
     (DATA(16),KR    ), (DATA(17),KPIN  ), (DATA(18),YINIT ),
     (DATA(19),YPRE  ), (DATA(20),ASIN  )
      EQUIVALENCE         (DATA(21),THIMP ), (DATA(22),THREL ),
     (DATA(23),THTCRU), (DATA(24),THRAM(1)),(DATA(27),THPIN(1)),
     (DATA(31),TH(1) ), (DATA(38),FSTRP1), (DATA(39),FSTRP2),
     (DATA(40),FLOCK1)
      EQUIVALENCE         (DATA(41),UR    ), (DATA(42),UT    ),
     (DATA(43),BB    ), (DATA(44),CB    ), (DATA(45),DB    ),
     (DATA(46),EB    ), (DATA(47),RPMT(1)),(DATA(67),TTAB(1))
C:     DEFINITION OF BUILT-IN CONSTANTS
C:      .74226=MAXIMUM SLOPE OF PARABOLIC PORTION OF CAM
C:      .12703=TOTAL CHANGE IN SLOPE OVER CYCLOIDAL PORTION OF CAM
C:      .1384=TOTAL AXIAL DISPLACEMENT(FEET)AT END OF CYCLOIDAL
C:             PORTION OF CAM
C:      .2747=TOTAL AXIAL DISPLACEMENT(FEET)AT END OF CONSTANT
C:             VELOCITY PORTION OF CAM
C:      .377=TOTAL AXIAL DISPLACEMENT(FEET) WHERE FIRING PIN SPRING
C:            COCKING BEGINS DURING REARWARD MOTION
C:      .0088=PRELOAD ON PIN SPRING(FEET)
C:      .329=TOTAL AXIAL DISPLACEMENT WHERE FIRING PIN SPRING
C:             CONTACT IS MADE DURING FORWARD MOTION
C:      .0375=DEFLECTION OF FIRING PIN SPRING WHEN CONTACT IS
C:           FIRST MADE DURING FORWARD MOTION
C:      .04533=MAXIMUM DEFLECTION OF FIRING PIN SPRING
      RPM=DTHETA/(PI*2.)*60.
      CALL TLKUP1(RPMT,RPM,20,KI,AY,Y,0,0,1,TTAB,TORQUE,ER)
      IQ=1; AFACT=1.0; TORQUE=TORQUE/192.; FLOCK=0.0
      THTA=THETA; THETA1=THETA; YPIN=0.0; FSTRIP=0.0; MASS=MC+MB
      IF(THETA.LT.2.*PI2) GO TO 2
      NCYCLE=THETA/(2.*PI2)
      THTA=THETA-2.*NCYCLE*PI2
      THETA1=THTA
    2 IF(THETA1.GT.THREL.AND.THETA1.LT.THIMP) MASS=MC
      IF(THETA1.LT.THRAM(1).OR.THETA1.GT.THRAM(2)) GO TO 4
      FSTRIP=FSTRP1
      IF(IMTEST.EQ.1) IN=0
      IMTEST=0
    4 IF(THETA1.GT.THRAM(2).AND.THETA1.LT.THRAM(3))FSTRIP=FSTRP2
      IF(THTA.GT.TH(3)) GO TO 6
      COF=1.
      YBOLT=ACAM*(THTA*RADIUS)**2
      GO TO 14
    6 IF(THTA.GT.PI2) GO TO 8
      THTA=PI2-THTA
      COF=-1.; IQ=2
      YBOLT=LCAM-ACAM*(THTA*RADIUS)**2
    7 IF(THTA.LE.TH(1)) GO TO 28
      GO TO 15
    8 IF(THTA.GT.TH(7)) GO TO 10
      THTA=THTA-PI2
      IQ=3
      YBOLT=LCAM-ACAM*(THTA*RADIUS)**2
      GO TO 18
   10 THTA=2.*PI2-THTA
      COF=-1.; IQ=4
      YBOLT=ACAM*(THTA*RADIUS)**2
      GO TO 7
   14 IF(IQ.EQ.1 .AND.THTA.LE. TH(1)) GO TO 23
      IF(THTA.GT.TH(2)) GO TO 16
   15 GAM=(THTA-TH(1))*PI/(2.*ASIN)
      AFACT=COS(GAM)
      DY=.74226+.12703*SIN(GAM)
      IF(IQ.EQ.1.OR.IQ.EQ.3) GO TO 24
      GO TO 29
   16 COF=1.0
      YBOLT=.1384+(THTA-TH(2))*RADIUS*TAN(ALPHA)
      GO TO 22
   18 IF(IQ.NE.3 .OR. THTA.GE.TH(1)) GO TO 20
      COF=-1.0
      GO TO 23
```

```
 20 IF(IQ.NE.3 .OR. THTA.GT.TH(2)) GO TO 21
    GO TO 15
 21 COF=-1.
    YBOLT=.2747-(THTA-TH(2))*RADIUS*TAN(ALPHA)
C:    STATEMENTS 22 THRU 27+2 ARE ACCELERATION EQUATIONS
 22 ALPHA=.72
    DDY=RADIUS*DDTHET*TAN(ALPHA)
    GO TO 25
 23 DY=2.*ACAM*RADIUS*THTA
 24 ALPHA=ATAN(DY)
    DDY=2.*ACAM*(RADIUS**2)*(DTHETA**2)*AFACT+RADIUS*DDTHET*DY
 25 IF(THETA.GT.THTCRU) YT=YPRE+YBOLT-YINIT
    IF(THETA1.LE.2.*PI2-THPIN(2).OR .IPIN.NE.1) GO TO 42
    IN=0 ; IPIN=0
 42 IF(THETA1.LT.2.*PI2-THPIN(3).OR.THETA1.GT.2.*PI2-THPIN(2))
     GO TO 26
    IPIN=1
    YPIN=ACAM*(THTA*RADIUS)**2-(LCAM-.377-.0088)
    FLOCK=1.5*FLOCK1
 26 BF=MASS*DDY+KS*YT+KPIN*YPIN+FSTRIP+FLOCK
    IF(BF.LT.0.) GO TO 31
 27 FN=-BF/(C1*SIN(ALPHA)+C2*COS(ALPHA))
    FCAM=FN*(SIN(ALPHA)+UR*COS(ALPHA))
    DDY=DDY*COF
    GO TO 40
 31 BF=-BF
    GO TO 36
 32 BF=-BF
GO TO 27
C:    STATEMENTS 28 THRU 36+3 ARE DECELERATION EQUATIONS
 28 DY=2.*ACAM*RADIUS*THTA
 29 ALPHA=ATAN(DY)
    DDY=2.*ACAM*(RADIUS**2)*(DTHETA**2)*AFACT-RADIUS*DDTHET*DY
    IF(THETA1.LT.THPIN(1).OR.THETA1.GT.THPIN(2))GO TO 30
    YPIN=.0375+LCAM-.329-ACAM*(THTA*RADIUS)**2
    FLOCK=FLOCK1; UCOEF=1.0; GO TO 35
 30 IF(THETA1.LT.THPIN(2).OR.THETA1.GT.THPIN(3))GO TO 35
    YPIN=.04533
    FLOCK=FLOCK1; UCOEF=0.3
 35 BF=MASS*DDY-FSTRIP-FLOCK-UCOEF*KPIN*YPIN
    IF(BF.LT.0.) GO TO 32
 36 FN=-BF/(C3*SIN(ALPHA)+C4*COS(ALPHA))
    FMUX=UR*FN*COS(ALPHA)
    FCAM=FMUX-FN*SIN(ALPHA)
    DDY=DDY*COF
 40 CONTINUE
    TBELT=WTBELT*RADSPR*(1.8*GFIELD+DDTHET*RADSPR/(12.*G))/12.
    TCAM=FCAM*RADIUS
    TFRICT=KT*DTHETA
    DDTHET=(TORQUE-TCAM-TFRICT-TBELT)/IEQUIV
    RETURN
    END
       BLOCK DATA
    COMMON/DATA1/DATA2(10),DATA3(30),DATA4(6),DATA5(40)
    DATA DATA2/1.6609,1.0, .11717, .0625, .75, 125.6667, .017811,
    .0118744, 6.4,.41308/
    DATA DATA3/.0000277, .00000165, .00087, 740.,.001,162852.,
    528., .0883, .045,.5585, 7.56564, 5.0, 100., 3.264,3.386,
    4.433,4.3633,4.4593,4.9742,0.,1.9199,2.4784,3.8048,4.3633,
    0.,0.,0.,20.0,6.8,2./
    DATA DATA4/.063, .125, 2.54, 1.72, .29, .58/
     DATA DATA5/0.0,100.,200.,300.,400.,500.,600.,700.,800.,975.,
1037.5,1112.5,1175.,1237.5,1287.5,1350.,1400.,1460.,1600.,1700.,
1120.,1110.,1100.,1070.,1030.,985.,930.,865.,785.,640.,560.,480.,
400.,320.,240.,160.,80.,0.,-320.,-600./
    END
```

```
          C:DPVN SUB. TO INTEGRATE BY ADAMS METHOD
      FUNCTION AINDV(T,DT,M,IN,N)
      DOUBLE PRECISION DT
      N=1
      IF(IN .NE. 0)GO TO 2
   1  M=0
      IN=1
   2  M=M+1
      IF(M-7)3,3,6
   3  GO TO(6,5,5,6,5,6,5),M
   5  AINDV=T
      RETURN
   6  AINDV=T+DT
      RETURN
      END
      FUNCTION DPNV(YS,DYS,DT,M,N)
      DIMENSION Y(20),DY(4,20), DY11(20)
      DOUBLE PRECISION DT,Y,DY,DY11,YY
      YY=YS
      DYD=DYS
      IF(M-7)8,8,9
   8  GO TO (10,11,12,13,14,15,16),M
  10  DY(2,N)=DYD
      Y(N)=YY
      XYY=Y(N)+DT*DYD
  17  DPNV=XYY
      N=N+1
      RETURN
  11  DY11(N)=DYD
      XYY=Y(N)+(DT/2.)*(DY11(N)+DY(2,N))
      GO TO 17
  12  XYY=Y(N)+(DT/6.)*(2.*DYD+DY11(N)+3.*DY(2,N))
      GO TO 17
  13  Y(N)=YY
      DY(3,N)=DYD
      XYY=Y(N)+(DT/2.)*(3.*DY(3,N)-DY(2,N))
      GO TO 17
  14  XYY=Y(N)+(DT/12.)*(5.*DYD+8.*DY(3,N)-DY(2,N))
      GO TO 17
  15  Y(N)=YY
      DY(4,N)=DYD
      XYY=Y(N)+(DT/12.)*(23.*DYD-16.*DY(3,N)+5.*DY(2,N))
      GO TO 17
  16  XYY=Y(N)+(DT/24.)*(9.*DYD+19.*DY(4,N)-5.*DY(3,N)+DY(2,N))
      GO TO 17
   9  DO 18 I=1,3
      II=I+1
  18  DY(I,N)=DY(II,N)
      DY(4,N)=DYD
      XYY=YY+(DT/24.)*(55.*DY(4,N)-59.*DY(3,N)+37.*DY(2,N)-9.*DY(1,N))
      GO TO 17
      END
      SUBROUTINE TLKUP1 (AX,X,LX,K,AY,Y,LY,J,NO,AC,ANS,ER)
      DIMENSION AX(20),AC(20)
  300 ER = 0.
      IF(K-1)310,310,311
  311 IF(AX(K)-X)316,313,313
  313 IF(AX(K-1)-X)390,317,308
  317 IF(K-2)312,390,312
  308 IF (K-2) 312, 307, 312
  307 WRITE(1,998) X, AX(K)
  998 FORMAT ( 1H 48HEXTRAPOLATION LOW  END, 2 D TABLE, VARIABLE 1=
     E15.6, 4X14HTABLE VALUE = E15.6 )
      GO TO 389
  310 K = 2
      GO TO 311
  316 IF(K-LX)315,309,310
  312 K = K-1
      GO TO 313
  315 K = K+1
      GO TO 311
```

```
309  WRITE(1, 999) X, AX(K)
999  FORMAT ( 1H 48HEXTRAPOLATION HIGH END, 2 D TABLE, VARIABLE 1=
      E15.6, 4X14HTABLE VALUE = E15.6)
329  ER = 1.0
390  XM = (X-AX(K-1))/(AX(K)-AX(K-1))
     DO 395 KOUNT=1,NO
     M = LX * (KOUNT - 1 ) + K
395  ANS = AC(M-1) + XM*(AC(M) - AC(M-1))
403  RETURN
     END
```